COLORADO
Division of Reclamation, Mining and Safety
Department of Natural Resources

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100000734

DATE: June 25, 2017

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RE: Report of Mine Hydrology Investigations and Dye Tracer Study, Illinois Gulch, Summit County, Colorado

Setting:
Illinois Gulch headwaters are on the northwest flank of Bald Mountain located to the southeast of the Town of Breckenridge in Summit County, Colorado. Illinois Creek flows in a west-northwesterly direction from the headwaters approximately 4.1 miles to the confluence with the Blue River in Breckenridge. Approximately three-fourths mile above the confluence of Illinois Gulch with the Blue River is the confluence of Illinois Gulch with Iron Springs Gulch. The headwaters of Iron Springs Gulch are within a historic abandoned mine complex that includes the Willard adit waste rock dump and is surrounded by and north of a prominent horseshoe curve in Boreas Pass Road (figure 1).

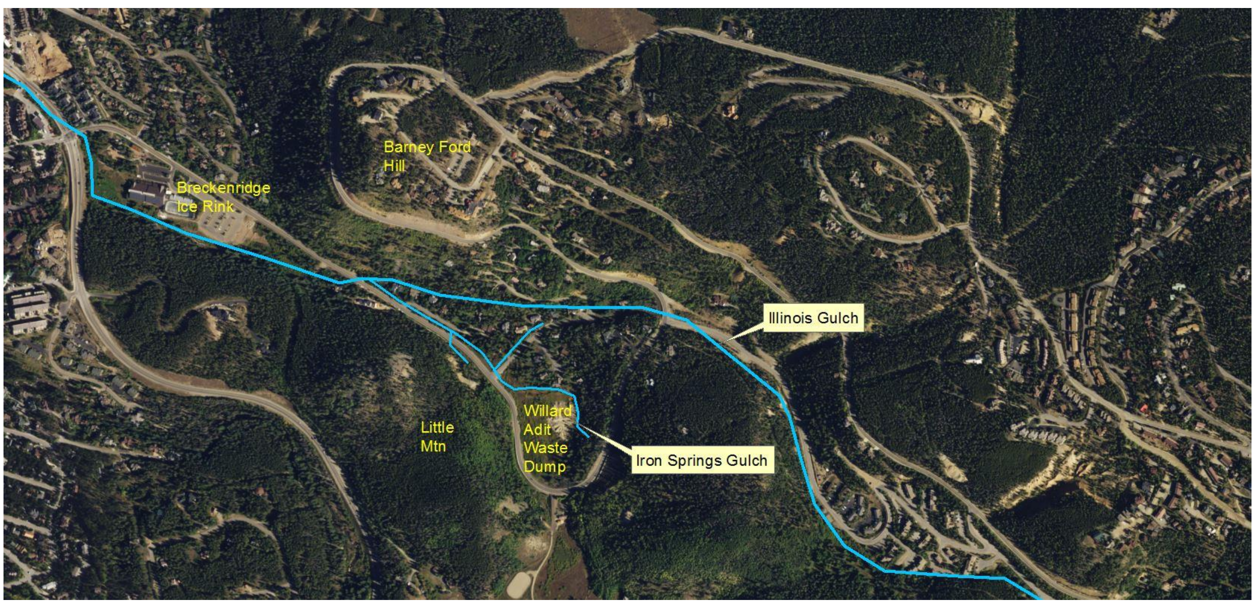


Figure 1: Location of Illinois Gulch

The headwaters of Iron Springs Gulch are comprised of inflows from springs, ground water seepage, and draining mines. The draining mines, and to a lesser degree some of the spring inflows and seepage into Iron Springs Gulch carry high concentrations of heavy metals and exhibit low pH typical of acid rock drainage caused by weathering of sulfide minerals. Mining activities that expose sulfide minerals to weathering processes and steepen ground water gradients by creating preferential flow paths though underground mine workings accelerate the formation of acid rock drainage and can increase and concentrate the flow of metalliferous water into surface streams. In particular, three inflows to Iron Springs Gulch characteristic of acid rock drainage were targeted by the investigation described in this report. These inflows are the draining mines called the Willard adit and Willard adit #2 and a ferruginous spring that has been dubbed the Cally spring. All three of these inflows are located around the perimeter of the prominent Willard adit waste rock dump shown in figure 1. Figure 2 illustrates the location of the inflow features relative to the waste rock dump and to the trace of the Willard adit crosscut and drifts denoted by the red lines on the figure.

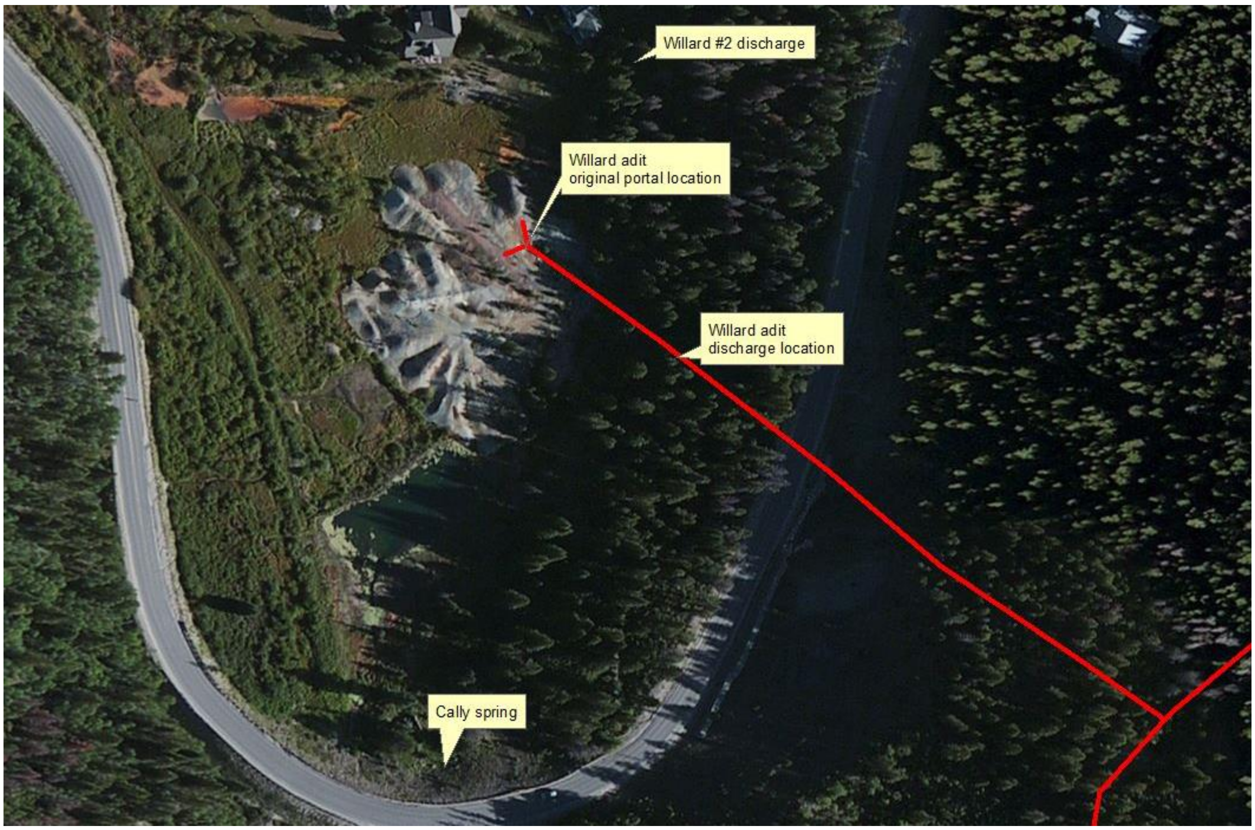


Figure 2: Inflows to Iron Springs Gulch located around Willard Mine Waste Dump

Illinois Gulch Water Quality

The Colorado Water Quality Control Commission has included Illinois Gulch on the list of impaired water bodies required under section 303(d) of the federal Clean Water Act. This listing is based on concentrations of dissolved zinc and cadmium that exceed water quality standards in Illinois Gulch below the confluence with Iron Springs Gulch. Since Illinois Gulch was placed on the 303(d) list, extensive additional environmental investigation and characterization has been conducted from 2011 through 2106 by a consortium of federal and state agencies and non-governmental organizations in cooperation with local government and landowners. Among the key findings of these investigations are:

1. Acid rock drainage entering Illinois Gulch is from a combination of naturally occurring geologic processes in highly mineralized zones and accelerated and intensified weathering of sulfide minerals as a result of historic mining throughout Illinois Gulch.
2. There are elevated concentrations of heavy metals in Illinois Gulch both above and below the confluence with Iron Springs Gulch. However, the greatest influx of heavy metals is from Iron Springs Gulch.
3. Acid rock drainage entering Illinois Gulch is from draining mines, naturally occurring and mining influenced springs and ground water seeps, and from runoff and seepage from mine waste rock piles.

<u>Mining of the Puzzle Vein:</u>
Ransome (1911) and Lovering (1934) describe the geology, ore deposits, and mining operations of Illinois Gulch. Much of the discussion in this section and the locations of underground mine workings and mineralized veins illustrated in the figures are derived from those publications. The south end of the Puzzle vein is located near the Wakefield Sawmill Museum, which is just south of the horseshoe curve in Boreas Pass Road. The vein, which is nearly vertical throughout its length, strikes east-northeast through the hillside to the east of the Willard mine dump and cuts through Illinois Gulch as shown on figure 3.

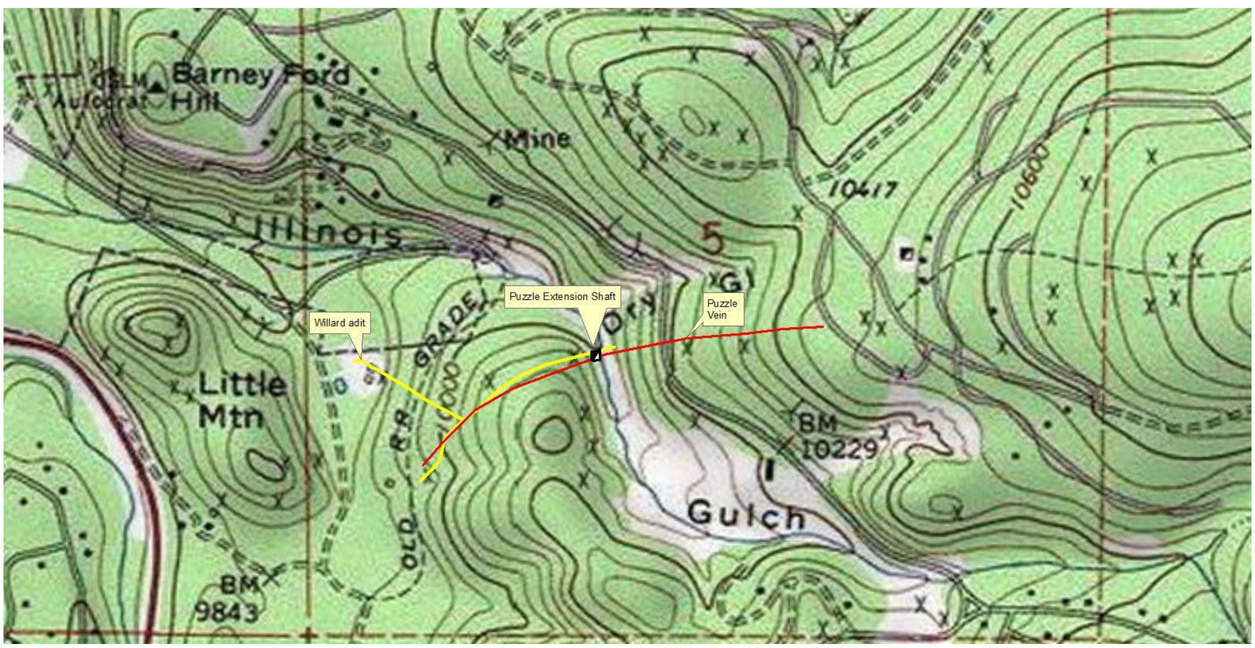


Figure 3: Surface Trace of the Puzzle Vein (Red) and Configuration of Part of the Willard Level Underground Workings – Crosscut Adit to, and the Drift along the Puzzle Vein (Yellow)

The southwest end of the Puzzle vein was staked under the Ouray claim, mineral survey no. 5654, with the rest of vein to where it intersects Illinois Gulch being staked under the Puzzle claim, mineral survey no. 5599, with much of the Ouray and Puzzle claims overlapping. The intersecting and overlapping claims on the same vein led to simultaneous mining of the Puzzle vein by two different mining companies operating side-by-side but using completely separate sets of mining infrastructure. Primary production occurred between 1888 and 1900, with production by the Ouray Mining and Milling Company ceasing in 1897 when litigation over ownership of the vein was settled in favor of the Puzzle Mining and Milling Company.

Remnants of the Ouray mine can be seen to the south of the horseshoe curve in Boreas Pass Road near the Wakefield Sawmill Museum (Twitty, 2004). A pair of side-by-side adits, now collapsed, extended southeast into the mountainside and served as main haulage way for the ore stoped from the Puzzle vein on the Ouray claim (figure 4). These are named the Cally adits, as the portals are on the Little Cally claim that was owned by the Ouray Company. Waste rock was dumped at the adit portals, and modern disturbance has removed the dump's center leaving two portions of the original dump separated by about 75 feet. Boreas Pass Road's fill-bank covers the northern portion of the dump. The Cally shaft was sunk from a location on a west facing slope several hundred feet east of and above the Cally adit portals (figure 4). The waste rock dump is substantial with a thickness of 15 feet at the downhill edge. The shaft is collapsed at the collar creating a crater 36 feet in diameter that drew in portions of the surrounding waste rock dump and the shaft house. The shaft was sunk to a depth 268 feet below the Cally adits haulage level. Two Cameron steam pumps were installed to dewater the shaft and stopes at depth. Deep ore from the Puzzle vein was hoisted to the Cally adit level by a 90-horsepower steam hoist located at the shaft collar, then trammed to surface via the adits, indicating that the shaft, adits, and stopes are all connected underground. The Wakefield Sawmill, which has been preserved as a museum, is located just southwest of the Cally adits. The sawmill has nothing to do with the mining operations, and was built and operated decades after the Ouray mine was shut down.

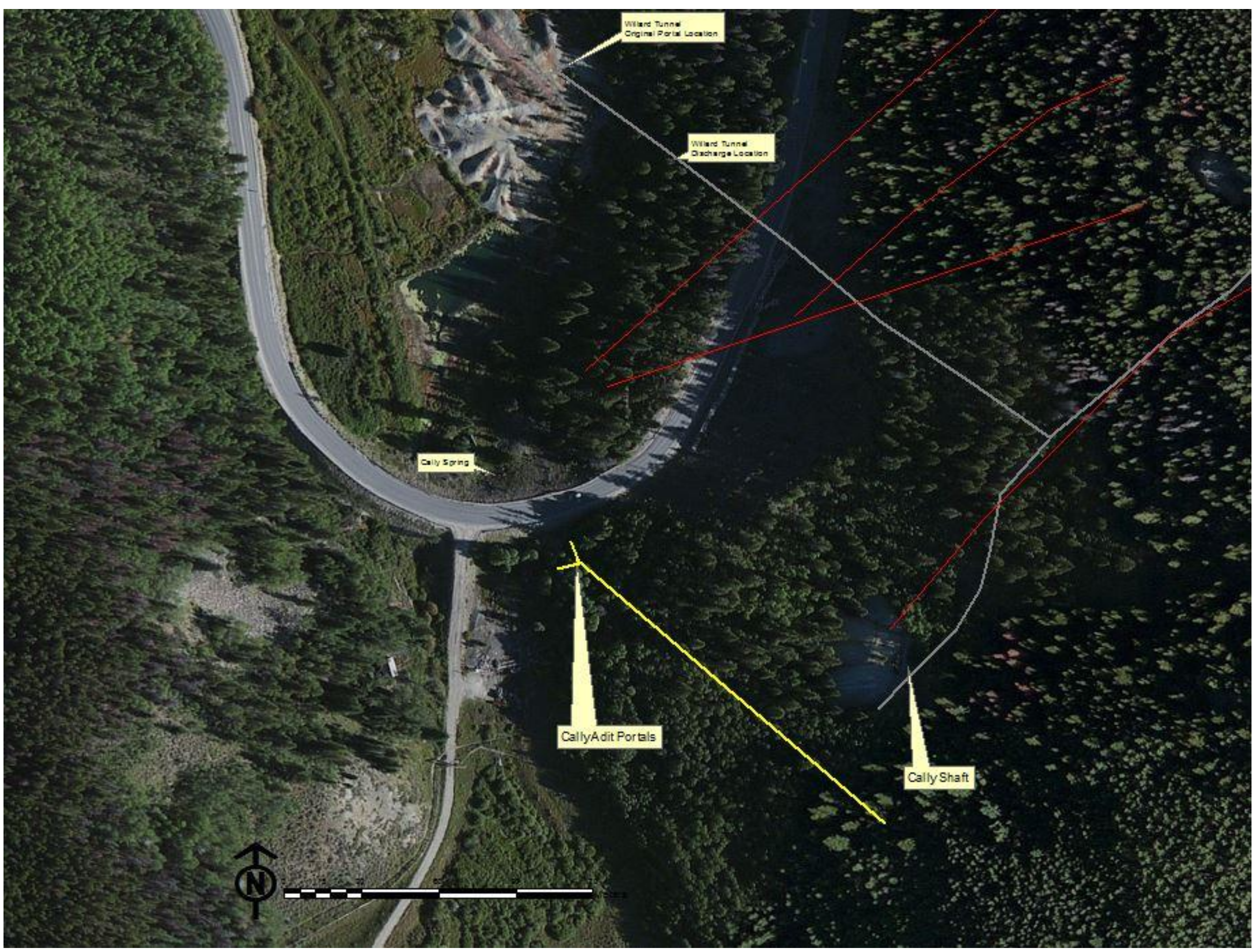


Figure 4: Location and Alignment of the Cally adits (yellow line) that served as the Main Haulage for the Ouray Mine. Location of the Collar of the Cally Shaft that Accessed the Puzzle Vein to Depths 268 Feet below the Main Haulage Level.

Remnants of the Puzzle mining operation can be seen can be seen north of the horseshoe curve in Boreas Pass Road, and include the large Willard adit mine waste dump. The Willard adit was the main haulage way and drainage for the Puzzle mine. It runs 715 feet southeast to the Puzzle vein and turns northeast on the vein, which it follows to and connects with the Puzzle Extension shaft (figures 3 and 4). The collar of the Puzzle Extension shaft, as it presently exists, is located immediately west and approximately ten feet above the bank of Illinois Creek. This is a two compartment shaft that was sunk to a depth of 187 feet. The Puzzle Extension shaft expresses itself at the surface as two side-by-side bowl shaped depressions at the top of the associated waste dump. The Willard adit and drifts and the Puzzle Extension shaft were developed by the Puzzle Company in the 1890s, and the Puzzle vein was completely stoped-out to the west of the Puzzle Extension shaft above the Willard level. By the late 1890s, with the rich ore exhausted, the Puzzle mine was turned over to lessees and production after that time was minimal.

In 1903, the owners of the Gold Dust mine located in Dry Gulch east of the Puzzle Extension shaft (figure 3), recognized that the Willard adit, if lengthened, could be used to access the Gold Dust vein at depth. To enact this plan, the Gold Dust owners leased a right-of-way through the Willard adit and drove a crosscut 300 feet in length from the Puzzle vein on the Willard level north to intersect the nearly parallel Gold Dust vein. From the intersection, the vein was drifted and stoped east and west over a length of 800 feet (figure 5). All of this work on the Gold Dust mine was done through the Willard adit, whose portal is in the headwaters of Iron Springs Gulch. The surface trace of the Gold Dust vein coincides with the bottom of Dry Gulch, and the Gold Dust shaft sunk in the 1880s and associated waste dump are situated in Dry Gulch.

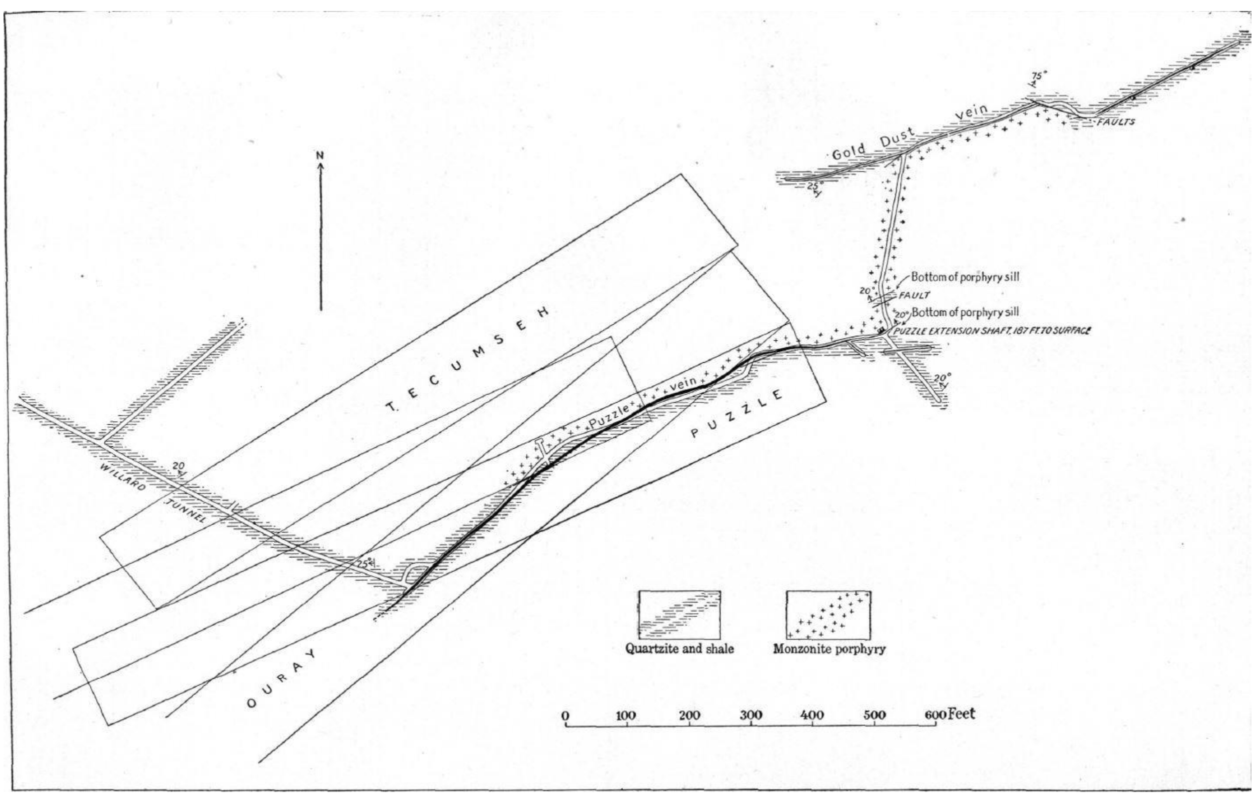


Figure 5: Geologic Plan of the Willard Level of the Puzzle and Gold Dust Mines, from Ransome, 1911

The descriptions of the mines provided above are not intended to be comprehensive descriptions of the operations of the Puzzle, Ouray, and Gold Dust mines. There are levels in those mines both above and below the Willard level that are not described in this report, and crosscuts to and drifts along other veins on multiple levels that are likewise not described. The limited descriptions of the mines are provided to facilitate understanding of how the mining operations may have impacted the headwaters of Iron Springs Gulch, particularly the inflows to the gulch from the Willard adit, Willard adit #2, and the Cally spring, as discussed below.

Creek Flows near the Puzzle Extension Shaft

The close proximity of the Puzzle Extension shaft to Illinois Creek, the known connection of the Willard adit to the shaft, and the perennial acid rock drainage from the Willard adit prompted an evaluation of the potential for creek water permeation into the shaft being a source of the discharge from the Willard adit. On October 7, 2015, EPA, DRMS, and EPA's ESAT contractor mobilized to Illinois Gulch and used velocity flow meters to simultaneously measure surface water flows in the creek upstream, downstream, and in the vicinity of the Puzzle Extension shaft, with the following results. These results are also illustrated in the figure 6 sketch.

> Flow in Illinois Creek approximately 330 feet upstream of Puzzle Extension shaft: 0.742 cubic feet per second
>
> Flow in Illinois Creek just upstream of Puzzle Extension shaft, where the Puzzle vein intersects the floor of Illinois Gulch, and upstream of springs that flow into the creek from the east: 0.456 cubic feet per second
>
> Flow in Illinois Creek approximately 300 feet downstream of Puzzle Extension shaft: 0.848 cubic feet per second

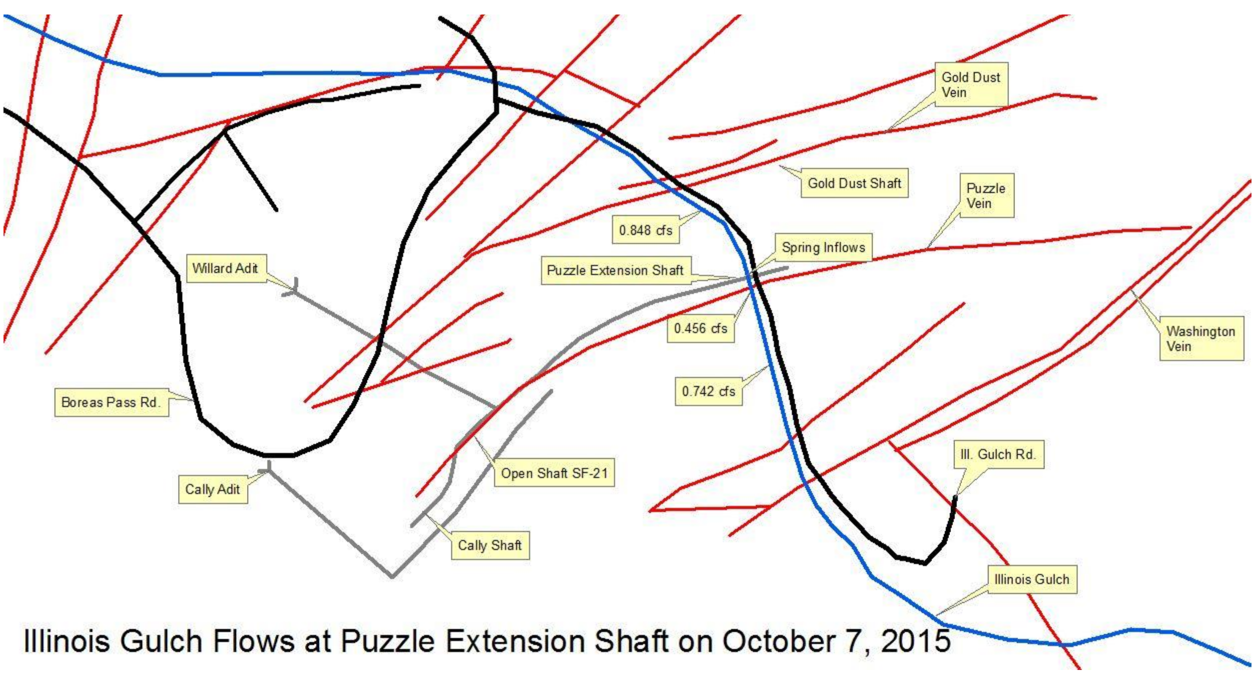
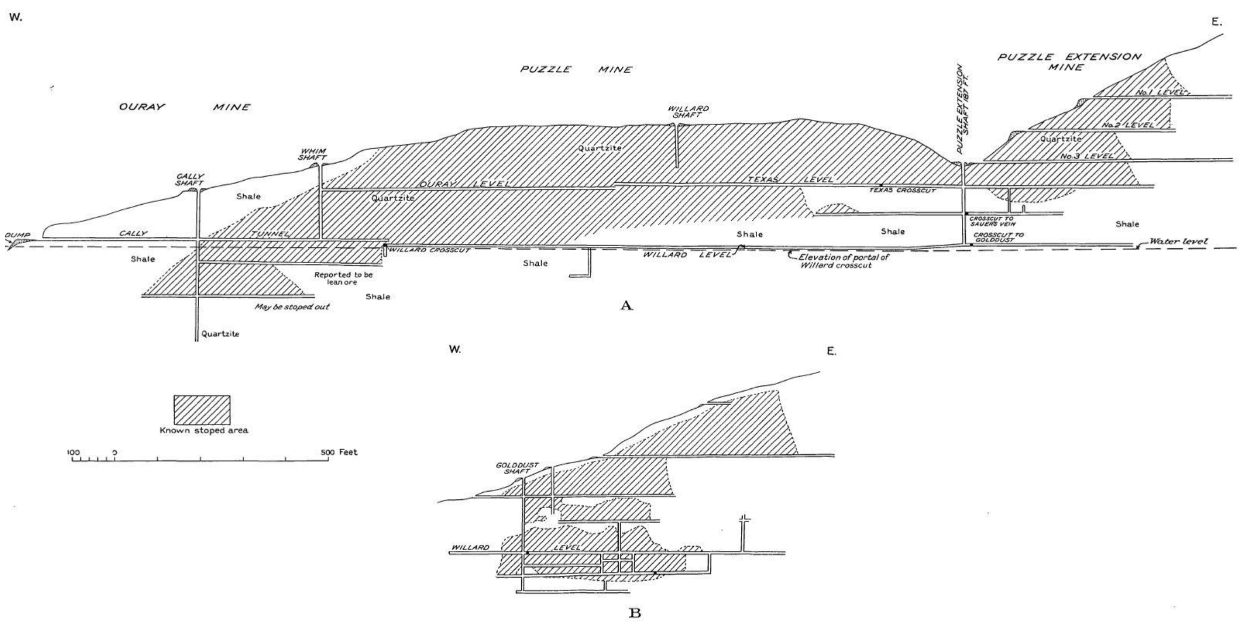


Figure 6: Note: Red Lines are Surface Traces of all Mapped Mineralized Veins within the Field of the Sketch, after Lovering, 1934

Figure 6 also depicts the location of spring inflows to the creek from the east. These springs had total flow of 8 gpm in October 2015 and carry elevated concentrations of heavy metals indicative of interaction with the mineralization in the Puzzle vein, potentially the Gold Dust vein, and the Puzzle Extension mine workings and waste dumps located east of the Puzzle Extension shaft (figure 7).



STOPE MAPS OF PUZZLE (A) AND GOLDDUST (B) VEINS.

Figure 7, from Lovering, 1934

The October 2015 flow measurements and observations of springs flowing into the creek from the east indicate the creek is losing flow through the reach where the Puzzle vein intersects the bottom of the gulch and the Puzzle Extension shaft is located on the creek bank. The measurements further indicate that the creek downstream of the Puzzle Extension shaft gains flow through springs and more significantly through seepage into the creek below the water surface. It was also recognized in planning the flow measurement exercise and in evaluating the results that these measurements would be of limited utility do to the difficulty of directly measuring flow in narrow, steep gradient, boulder strewn streams, and the inability of these types of measurements to capture hyporheic flow, which in the reach under investigation appears to be significant. The usefulness of the October 2015 measurements was the encouragement they provided to further the investigations of a potential flow path for creek water through the Puzzle Extension shaft and Puzzle vein and via the Puzzle mine underground workings to the headwaters of Iron Springs Gulch.

The USGS was engaged to leverage that organizations expertise in using continuous and slug injections of salts into streams to accurately determine flows and establish flow pathways. Plans for the USGS to conduct an intensive quantitative investigation were assembled over the winter and the investigation was scheduled for August into September of 2016. The results and findings of that investigation will be reported on separately. In addition to the USGS investigation using salt tracers, it was determined that a dye tracer test would be conducted in June and July of 2016 with the following objectives:

1. Determine if a hydrologic flow path is present that would transmit water injected into the Puzzle Extension shaft to the headwaters of Iron Springs Gulch.
2. Instruct the planning for duration of the USGS investigation in terms of transit times for water originating near the Puzzle Extension shaft to the headwaters of Iron Springs Gulch.

Planning for the Dye Tracer Test

Three inflows to the headwaters of Iron Springs Gulch were targeted for investigation, the Willard adit, Willard adit #2, and the Cally spring.

Willard adit: Of the three inflows targeted for investigation, the most is known about the Willard adit. The underground workings have been mapped and the connection to the Puzzle Extension shaft is well documented. A dedicated flume and data logging transducers were installed at the Willard adit on 9/11/15. The transducers were downloaded on 8/18/16. The high flow during that period of record was 63 gpm on 6/23/16, and the low measured flow was 20 gpm on 11/30/15. Flow during the term of the dye tracer test fluctuated between 35 and 63 gpm (6/20/16 to 7/5/16). The first 150-200 feet of the Willard adit, from the original 1890s portal location to the current discharge location, are caved-in and collapsed to the surface (figure 2). The collapsed section of adit forms a V-shaped notch into the hillside constricting at the east, uphill end where the drainage is emerging. Cap and post timbering are still standing and visible near the drainage location, the configuration of which indicate that the drainage is emerging at an elevation approximately six feet above the back, or roof of the adit. This indicates that the adit is impounding ground water and is flooded for some considerable distance inby the surface discharge. A major surge release from the Willard adit of impounded ground water occurred in April 2006.

Willard adit #2: Very little is known about the Willard adit #2. No maps or literature for this adit have been located to date. The adit is collapsed at the portal and there is a small crown hole beginning to cave-in a short distance above to the east. From the configuration of the portal as it is faced-up into the hillside, and the location of the crown hole, it appears that the adit was initially driven bearing N82^{O}E, as illustrated on figure 8. Also apparent on figure 8 is that this bearing is divergent from the trace of the Willard adit #1, and that there are mineralized veins on the N82^{O}E bearing that may have been the target of the Willard adit #2. There is little or no mine waste rock dumped in the immediate vicinity of the Willard adit #2 to give an indication of the depth to which it was driven. It may be that the waste rock has been removed, possibly as part of the nearby residential development, or that the waste was trammed off and dumped on the large and nearby Willard dump, or that the Willard #2 is a very shallow adit, although the perennial discharge tends to argue against the adit being shallow. A dedicated flume and data logging transducer were installed at the Willard adit on 10/9/15. The transducer was downloaded on 8/18/16. The high flow during that period of record was 65 gpm on 6/20/16, and the low measured flow was 16 gpm on 10/23/15. However, much of the data collected in the winter were not usable. Flow during the term of the dye tracer test fluctuated between 31 and 65 gpm (6/20/16 to 7/2/16).

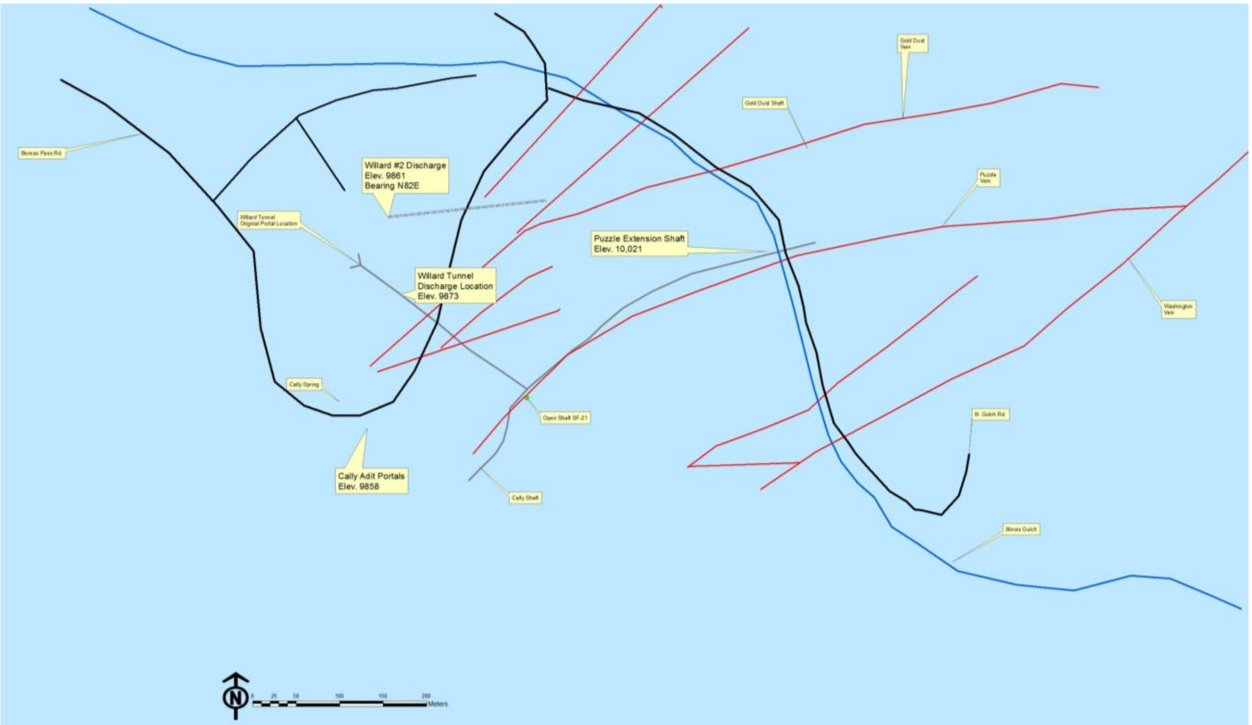


Figure 8: Willard Adit #2 Portal Location and Orientation. Extent of the Adit at this Orientation is Speculative. Red Lines are Surface Traces of Selected Mineralized Veins. For an Illustration of all known Veins within the Field of the Sketch see Figure 6.

Cally spring. Early in the planning process for the Illinois Gulch mine hydrology investigations, it was surmised that flow from the Cally spring might be a discharge from the Ouray mine workings, and it remains a possibility that the flow has been impacted by the mine, and a likelihood that the water quality of the flow has been impacted by the mineralization associated with the Puzzle vein. As discussed previously, the Cally adit portals of the Ouray mine were definitively located and mapped by the investigative team in August 2016. The Cally adit portals are approximately 140 feet southeast of the Cally spring on the opposite side of Boreas Pass Road (figure 4). The Cally adit portals are dry. It is possible, even likely, that the Cally spring is the modern manifestation of the spring described by Ransome, 1911, in the following quotation:

> …iron is taken up by the ground water in any reaction involving the replacement of pyrite by sphalerite or galena, so that any of this water emerging as springs…is likely to be highly ferruginous, as is that of a spring near the Puzzle and Ouray mines.

The DRMS measured flow at the Cally spring twice during the conduct of the dye tracer study. Flow was 9.9 gpm on 6/27/16 and 9.9 gpm again on 6/29/16.

Dye Selection: Uranine dye, $C_{20}H_{12}O_5$, was the primary dye selected for use in the dye tracer study, and rhodamine WT was used as a secondary dye. Uranine and rhodamine WT are non-hazardous, and in low concentrations dissolved in water, non-toxic (Field, *et al.*, 1995). Uranine was selected as the primary tracer because its low sorptive properties and stability in low light settings make it ideal for tracking ground water movement. Rapid degradation of uranine when exposed to sunlight would minimize the potential for visual disturbance of significant duration if visible concentrations of uranine dye were to be released to surface streams. Rhodamine WT was selected as the secondary dye for this investigation because it is highly visible when present in surface water, making it ideal for the purpose of determining if there are any direct, rapid flow paths from the injection point to surface streams, as described below.

In order to determine the amount of the primary uranine tracer to inject into the Puzzle Extension shaft, the guidelines presented in Wolkersdofer, 2008 were considered, including the following equation:

$$m = \frac{(V_m + Q \ x \ t)C_{min}}{r_r}$$

Where:
m is the tracer amount in grams
V_m is the mine pool volume in cubic meters
r_r is the recovery rate
Q is the discharge in liters per minute
t is the test duration in minutes
C_{min} is the detection limit of the tracer in grams per liter

However, with no information prior to the test on the velocity of flow through the mine workings, t could not be determined. There was insufficient information prior to the conduct of the test to determine r_r and only limited information relative to a determination of V_m. Therefore, the statement in Wolkersdofer, 2008 that "the empirical values deduced from the experiences of the working group play an important role in calculating the necessary tracer amount" guided the determination of the amount of uranine to be injected.

The basic considerations for the amount of uranine dye to be used in the investigation were:

1. Sufficient dye so that it would be detectable by a field fluorimeter if and when it emerged at the headwaters of Iron Springs Gulch.
2. Limits on the amount of dye to assure that it is released to surface streams in concentrations below toxicity thresholds and to prevent undue visual impact.

The EPA commissioned a mine hydrology investigation at the Rico Argentine mine site in Dolores County Colorado in 2011. The Rico Argentine investigation employed multiple tracers including uranine, and is described in Cowie, *et al.*, 2014. The Rico Argentine investigation included a similar objective to the Illinois Gulch investigation, in that uranine was injected into the 517 shaft of the Rico Argentine mine to determine if and how that shaft is hydrologically connected to the St. Louis tunnel that discharges to the Dolores River. The amount of uranine injected into the 517 shaft and the concentrations that were measured at the St. Louis tunnel were used to calculate the amount of uranine to be injected into the Puzzle Extension shaft that would conform to the above listed considerations. With a target concentration for uranine at potential discharge points in Iron Springs Gulch of 500 parts per billion (ppb), well below levels where toxicity would be an issue (Field, *et al.*, 1995), the amount of uranine to be injected was calculated as follows.

Ratio of uranine injected to resultant concentration at discharge point(s):

30 pounds uranine injected into 517 shaft. 2900 ppb peak concentration at St. Louis tunnel

30 pounds / 2900 ppb = x / 500 ppb x = 5.17 pounds uranine, based on a straight ratio and targeted peak uranine concentration at discharge to Iron Springs Gulch.

Ratio of flows at uranine discharge points:

1.25 cfs at St. Louis tunnel. 0.2 cfs into Iron Springs Gulch additive from Willard and Willard #2 adits and Cally Spring.

0.2/1.25 x 5.17 pounds = 0.83 pounds uranine to be injected.

Other considerations relative to the amount of uranine to be injected down the Puzzle Extension shaft were:

1. A more torturous flow path via the caved and collapsed Puzzle Extension shaft compared to the intact and open 517 shaft.
2. Approximately 50,000 gallons of so-called chase water was pumped down the 517 shaft over a 30 minute period immediately following uranine injection. A comparatively insignificant amount of chase water was pumped down the Puzzle Extension shaft following uranine injection as will be described below.
3. The flow path via mine workings from the 517 shaft to the St. Louis tunnel portal is approximately 9000 feet, compared to an approximately 1800 foot flow path from the collar of the Puzzle Extension shaft to the headwaters of Iron Springs Gulch.

Listed considerations numbered 1 and 2 would indicate that a relatively larger amount of uranine would be required at the Puzzle Extension shaft injection point than at the 517 shaft, and consideration number 3 would indicate that less uranine would be required. These factors were determined to be offsetting given the difficulty of assigning weighting due to the unknowns within the subsurface conditions of the Puzzle mine. Mine water chemistry was also determined to be a nonfactor in determining the amount of uranine to be injected as both the Rico Argentine and Puzzle mines contain and transmit similar acidic metalliferous water typical of acid rock drainage. Based on the foregoing calculations and considerations, it was determined that 0.8 pounds or 363 grams of uranine would be injected into the Puzzle Extension shaft.

Injection of the Dye Tracers

On June 20, 2016, a multi-agency team assembled in Illinois Gulch to inject the dyes into the Puzzle Extension shaft and to set-up the sampling and monitoring equipment in the headwaters of Iron Springs Gulch. The sampling and monitoring facilities were setup as follows:

Willard adit: Parshall flume with stilling well and dedicated transducer. Flow measurement collected every four hours. ISCO automated water sampler. Water sample collected once per hour beginning at 1045 on 6/20/16 then every two hours beginning at 1045 on 6/23/16 then every six hours beginning at 1050 on 6/29/16 and continued through 0450 on 7/5/16.

Willard adit #2: Parshall flume with stilling well and dedicated transducer. Flow measurement collected every four hours. ISCO automated water sampler. Water sample collected once per hour beginning at 1135 on 6/20/16 then every two hours beginning at 1135 on 6/23/16 then every six hours beginning at 1135 on 6/29/16 and continued through 0535 on 7/2/16.

Cally spring: Cutthroat flume installed and levelled on 6/20/16 and removed at 1040 on 6/29/16. Periodic flow measurements collected during the course of the investigation. ISCO automated water sampler. Water sample collected once per hour beginning at 1235 on 6/20/16 then every two hours beginning at 1235 on 6/23/16 then every six hours beginning at 1235 on 6/29/16 and continued through 0635 on 7/5/16.

For all three of the sampling locations, the Cyclops 7 field fluorimeter manufactured by Turner Designs, Inc. was employed to measure uranine concentrations in the samples collected by the ISCOs. Standard solutions for fluorimeter calibration were prepared at the EPA laboratory in Golden, Colorado.

In order to prepare for dye injection into the Puzzle Extension shaft, a harnessed and roped-off crew accessed the collar of the north shaft compartment and hammered a soil sampling tube into the mine waste that fills the depression of the collapsed shaft compartment. The two foot column of mine waste collected in the sampling tube consisted of yellowish and reddish brown coarse grained sand sized material. The sample hole remained open, and a plastic sleeve was inserted. The sleeved hole would be used for injection of fluids for the duration of the dye tracer investigation.

A pumping and dye mixing station was established on top of the mine waste dump adjacent to the Puzzle Extension shaft collapse crater. A small battery powered peristaltic pump was setup with intake and discharge tubing arranged so that creek water could be pumped into new, clean plastic buckets at the mixing station, or could be pumped directly into the injection point established in the shaft. Using a graduated bucket and stop watch, it was determined that the pump was operating at a rate of 9.2 gallons per hour drawing creek water up to the mixing station.

Rhodamine WT was the first dye to be injected. The purpose of the Rhodamine WT injection was to determine if there were any direct, rapid flow paths from the injection point through the creek bank and into Illinois Creek. This test was done using a small amount of dye so that if it did follow a short flow path directly to the creek, it would be visible and provide the needed information, but would also be rapidly diluted in the creek water to minimize visual impacts downstream. This test was necessary prior to injection of the primary dye tracer, which would be injected in a much greater amount and would cause an unacceptable visual disturbance if it followed a short flow path directly to the creek.

One fourth (0.25) pounds of pure rhodamine WT dissolved in 110 milliliters (ml) concentrated solution was obtained from Keystone Aniline Corporation, Chicago, Illinois. At an offsite location, the Breckenridge Ice Rink parking lot, 13.75 ml of concentrated solution was withdrawn from the rhodamine WT bottle using a graduated syringe. This volume of concentrated solution containing one-half ounce of pure dye was poured into a new, clean five gallon plastic bucket that was sealed and transported to the Puzzle Extension shaft. The bucket was unsealed, and the concentrated dye solution was mixed with approximately two gallons of creek water. The mixture was injected down the Puzzle Extension shaft between 1200 and 1214 hours on 6/20/16. The creek adjacent to and downstream of the Puzzle Extension shaft was inspected during the two hours following rhodamine WT injection and no dye was observed, providing confidence that no direct, rapid flow path from the injection point to the creek was present and allowing for the safe injection of the primary dye.

Figure 9: Photograph showing the Collapsed Two-Compartment Puzzle Extension Shaft, the Pumping and Dye Mixing Station Established at the Shaft Collar, and the Close Proximity of the Creek to the Shaft.

Several gallons of concentrated uranine dye solution was obtained from Abbey Color, Inc., Philadelphia, Pennsylvania. The assay sheet provided by the manufacturer stated that the solution was 41.2 percent pure uranine by weight. As presented above, it had been determined that approximately 0.8 pounds, or 363 grams of pure uranine would be injected. From the assay, the amount of concentrated solution to be injected was calculated as follows:

363 grams pure dye / 41.2 percent = 881.1 grams concentrated solution to be injected

A mechanical triple beam scale was setup and zeroed at the pumping and mixing station, and four batches of concentrated uranine solution were weighed and poured into a new, clean plastic bucket. The four batches totaled 889.69 grams of concentrated solution that was then mixed with approximately four gallons of creek water and this mixture was injected down the Puzzle Extension shaft starting at 1400 and ending at 1413 hours on 6/20/16. Following the injection of the dye, the peristaltic pump was rigged to pump creek water into the injection point in order to chase the dye solution down the collapsed shaft. The rate of chase water injection was approximately ten gallons per hour. A much higher rate of chase water injection would have been more effective in moving the dye through the collapsed shaft and flooded mine workings, but the potential to further destabilize the collapsed shaft by pumping large volumes of water into it prevented the use of higher chase water injection rates. Also, employment of chase water at a low rate of flow was advantageous as it would more effectively demonstrate if creek water is flowing down the collapsed Puzzle Extension shaft, as it would be this creek water, rather that high flow rate chase water, serving as the carrier for uranine dye detected at the monitoring stations.

Monitoring in Iron Springs Gulch and Results

As discussed above, the Willard adit, Willard adit #2, and Cally spring discharges were monitored for detection of uranine dye before and after injection of the dye down the Puzzle Extension shaft. During the course of the investigation, no dye was detected at either the Willard adit #2 nor at the Cally spring. There was one detection of uranine at the Cally spring in the sample collected at 1835 hours on June 30, 2016, but this was determined to be a false positive because of the non-detects in the samples collected six hours prior and six following, and the certainty that dispersion of the dye ten days following initial injection would not allow such an isolated detection.

Positive detection of uranine dye did occur in the Willard adit discharge. Figure 10 is a plot of uranine concentrations at the Willard adit over the course of the investigation. Very low concentrations of uranine dye were detected in the Willard adit discharge prior to the injection of dye into the Puzzle Extension shaft. Uranine dye is used in antifreeze and other common preparations, so the pre-existing uranine that was detected could be due to the presence of uranine in Illinois Gulch from paved surfaces runoff and other sources unrelated to the investigation. Uranine dye was detected in very low concentrations at the Willard adit throughout the course of the investigation. The concentrations were sufficiently low to prompt the consideration that the detections were not related to the injection of uranine into the Puzzle Extension shaft. However, the results of the salt tracer study conducted by USGS that is the subject of a separate report, combined with the consistency of the rise and fall in uranine concentrations as illustrated on the plot shown in figure 10 lend confidence to the conclusion that the elevated dye concentrations were from the dye that was injected.

The following conclusions are drawn from the data.

1. First detection of the uranine dye injected into the Puzzle Extension shaft in the Willard adit discharge appears to have occurred approximately 46 hours following injection.

2. There is a hydrologic flow path from Illinois Creek through the Puzzle Extension mine and Puzzle mine workings to the Willard level of the Puzzle mine and the Willard adit portal to the headwaters of Iron Springs gulch.

3. Less than five percent of the dye injected into the Puzzle Extension shaft issued from the Willard adit during the course of the investigation. It is likely that much of the dye was deterred in the pore spaces of the mine waste collapsed into the shaft, and that additional chase water would have moved a greater percentage of the dye through the system.

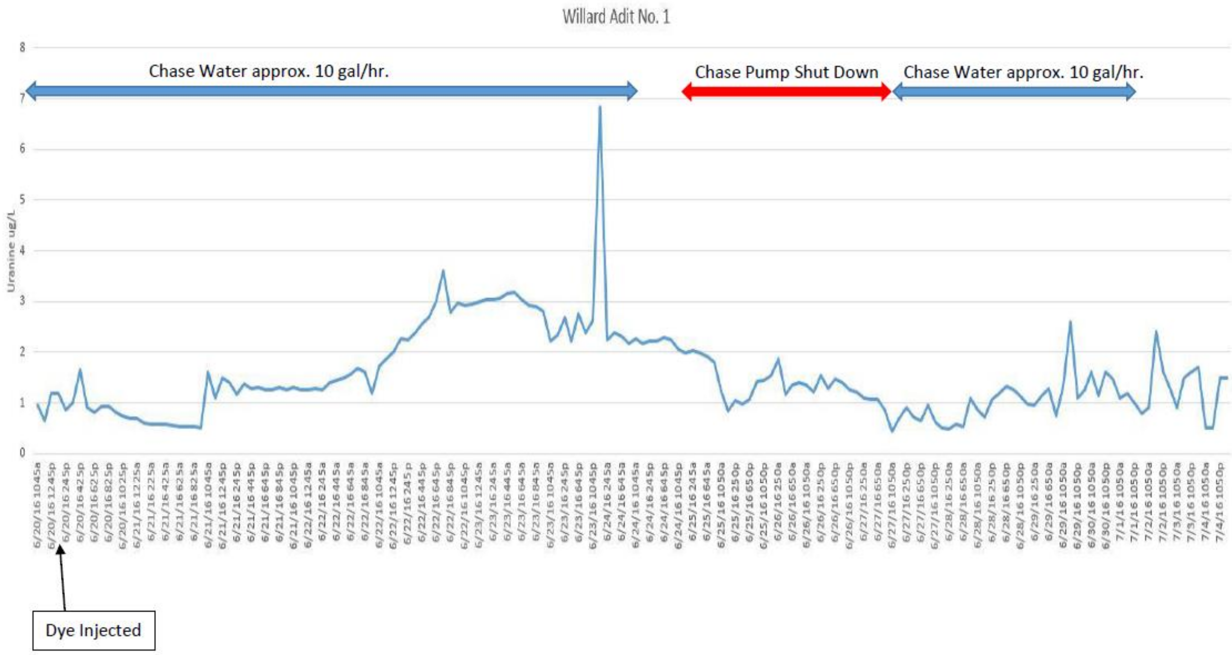


Figure 10: Plot of Uranine Concentration in the Willard Adit Discharge

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